NEOSHO BASIN TOTAL MAXIMUM DAILY LOAD

Waterbody/Assessment Unit: Tar Creek
Water Quality Impairment: Lead, Cadmium and Zinc

1. INTRODUCTION AND PROBLEM IDENTIFICATION

Subbasin: Lake O' The Cherokees **County:** Cherokee

HUC 8: 11070206

HUC 11 (HUC 14s)**:** **010** (060)

Drainage Area: 16.4 square miles

Main Stem Segment: WQLS: 19 (Tar Creek) starting at the Kansas-Oklahoma state line and traveling upstream to the headwaters in south-central Cherokee County (**Figure 1**).

Designated Uses: Expected Aquatic Life Support, Food Procurement, Groundwater Recharge, Livestock Watering and Secondary Contact Recreation on Main Stem Segment.

Impaired Use: Expected Aquatic Life Support

Water Quality Standard: Hardness-dependent criteria (KAR 28-16-28e(c)(2)(F)(ii)). Chronic Aquatic Life (AL) Support formulae are: (where Water Effects Ratio = WER is 1.0 and hardness is in mg/L)

Chronic AL Total Cadmium (Fg/liter) = WER[EXP[(0.7852*(LN(hardness)))-2.715]]

Chronic AL Total Lead (Fg/liter) = WER[EXP[(1.273*(LN(hardness)))-4.705]]

Chronic AL Total Zinc (Fg/liter) = WER[EXP[(0.8473*(LN(hardness)))+0.884]]

2. CURRENT WATER QUALITY CONDITION AND DESIRED ENDPOINT

Level of Support for Designated Use under 2002 303(d): Not Supporting Aquatic Life

Monitoring Sites: Station 110 at Picher, Oklahoma

Sampling Station Period of Record: 1993, 1997 and 2001 for Station 110 (**Figures 2, 3 and 4**)

Flow Record: Regression analysis (**Figure 5**) was used to create estimated flows for Tar Creek at Picher, Oklahoma, based on a bivariate fit of the flow record for Tar Creek at Miami, Oklahoma (USGS Station 07185100; 1980-1984, 07185095; 1984-1993) by Lightning Creek near McCune (USGS Station 07184000; 1980-1993). The estimated flow at the Tar Creek Miami site was portioned to the drainage for Tar Creek at Picher, Oklahoma.

Long Term Flow Conditions: 10% Exceedance Flows = 18.2 cfs, 95% = 0.28 cfs

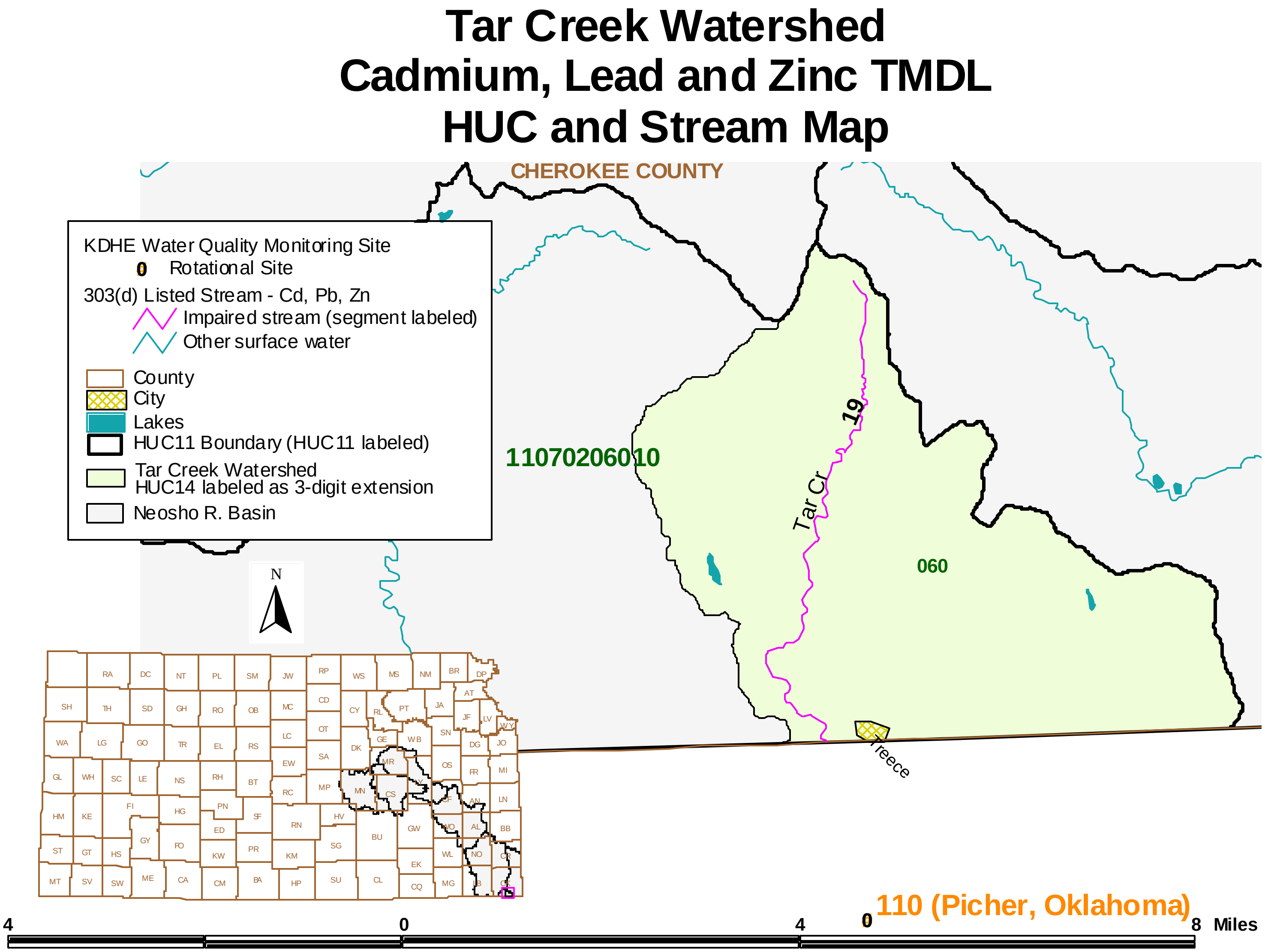


Figure 1

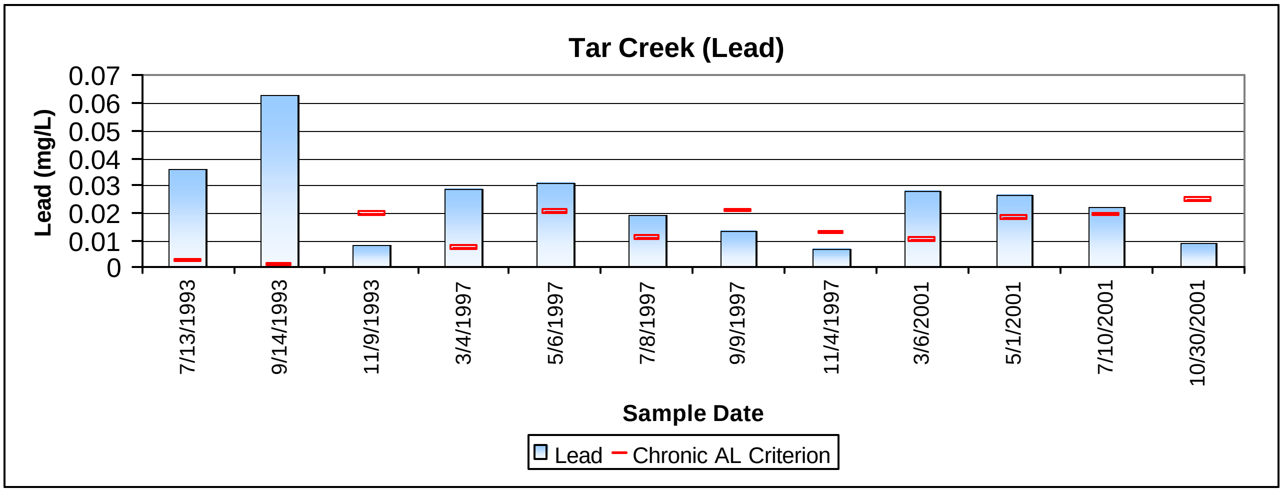


Figure 2

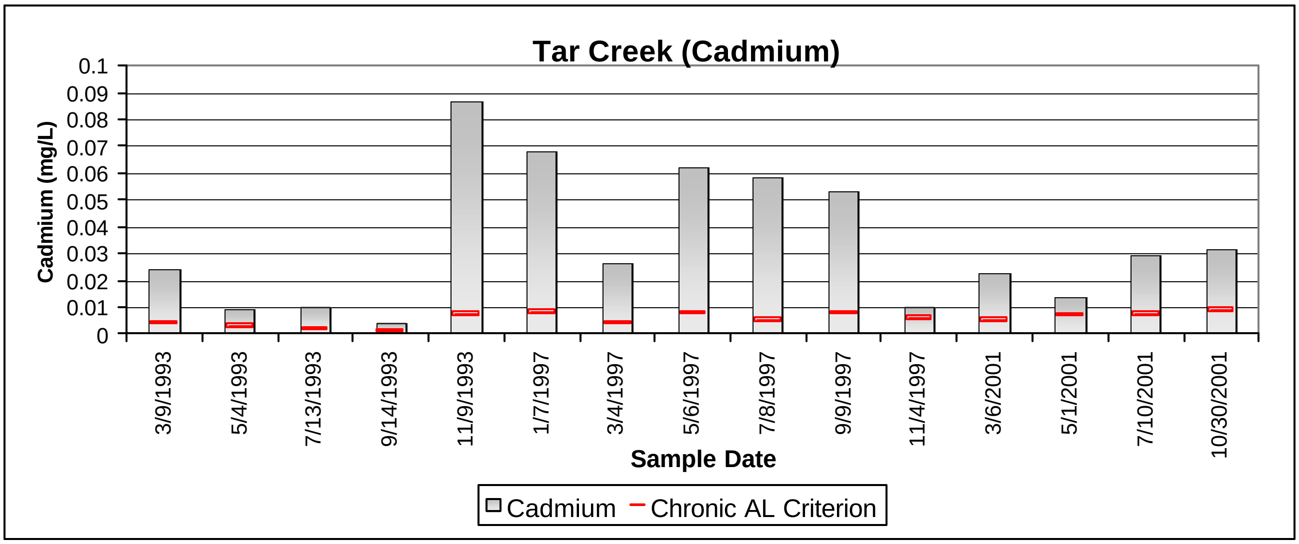


Figure 3

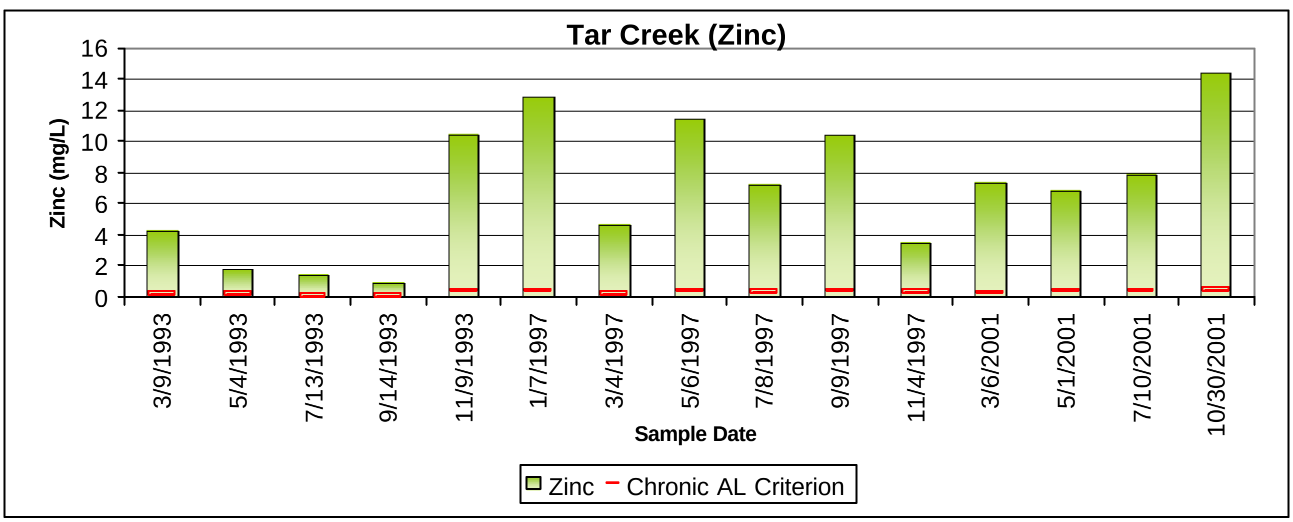
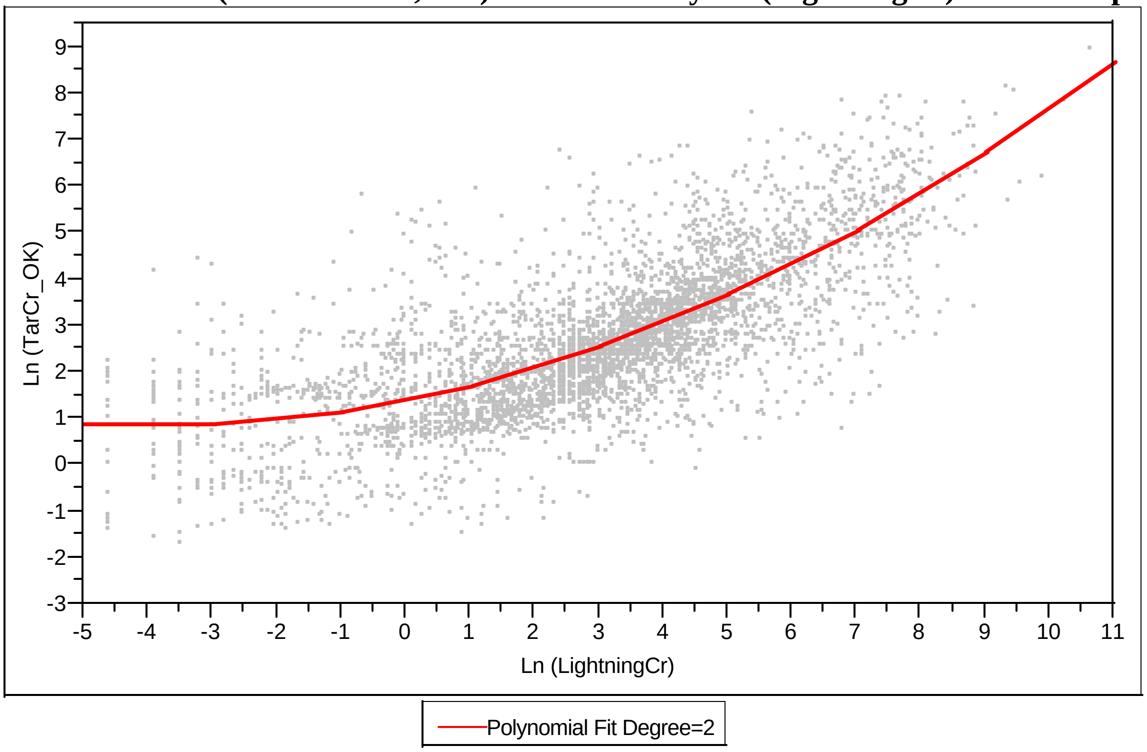


Figure 4

Bivariate Fit of Ln (TarCr Miami, OK) 1980 – 1993 By Ln (LightningCr) same time period



Polynomial Fit Degree=2

Ln (TarCr_Miami, OK) = 1.3319793 + 0.2800313 Ln (LightningCr) + 0.0346649 Ln (LightningCr)^2

Summary of Fit

RSquare	0.557643
RSquare Adj	0.557438
Root Mean Square Error	1.058952
Mean of Response	2.664922
Observations (or Sum Wgts)	4310

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	6088.513	3044.26	2714.74
Error	4307	4829.785	1.12	Prob > F
C. Total	4309	10918.298		0.0000

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.3319793	0.024435	54.51	0.0000
Ln (LightningCr)	0.2800313	0.010348	27.06	<.0001
Ln (LightningCr)^2	0.0346649	0.001721	20.15	<.0001

Figure 5

Current Conditions: Since loading capacity varies as a function of the flow present in the stream, this TMDL represents a continuum of desired loads over all flow conditions, rather than fixed at a single value. High flows and runoff equate to lower flow durations; baseflow and point source influences generally occur in the 75-99% range. Since chronic AL criteria for lead, cadmium and zinc are dependent on total hardness, analysis curves were established for the Chronic Aquatic Life criterion by subtracting the calculated criterion from the observed sample concentration from Site 110 for Tar Creek at Picher, Oklahoma. Doing so standardizes each sample in a watershed by their magnitude (positive for excursions and negative for compliant samples) from the calculated criteria. In addition, the analysis curve graphically displays water quality conditions at various flows. A reference line at zero on the Y-axis approximates the TMDL for the watershed. Positive points plotting above this line are historic excursions from water quality standards (WQS) and negative points plotting below the zero line represent compliant samples. This relationship between magnitude of deviation from water quality criteria by flow condition is explored further below.

Tar Creek Lead Samples: Sample data were categorized into three defined seasons: Spring (Apr-Jul), Summer-Fall (Aug-Oct) and Winter (Nov-Mar). Excursions were seen in each of these three defined seasons and are outlined in **Table 1**. All of the Spring samples and 33% of Summer-Fall samples were above the chronic aquatic life criterion. Fifty percent of the Winter samples were over the chronic aquatic life criterion. Overall, 66% of the samples were over the criterion. This would represent a baseline condition of non-support of the impaired designated use.

Table 1

NUMBER OF SAMPLES OVER LEAD CHRONIC AQUATIC LIFE CRITERION BY FLOW								
Station	**Season**	**0 to 10%**	**10 to 25%**	**25 to 50%**	**50 to 75%**	**75 to 90%**	**90 to 100%**	**Cum. Freq.**
Tar Cr at Picher, Oklahoma (110)	Spring	1	0	0	4	0	0	5/5 = 100%
	Summer/Fall	1	0	0	0	0	0	1/3 = 33%
	Winter	0	0	2	1	1	0	2/4 = 50%

Tar Creek Cadmium Samples: Using the three defined seasons: Spring (Apr-Jul), Summer-Fall (Aug-Oct) and Winter (Nov-Mar), excursions were seen in each of these seasons and are outlined in **Table 2**. All of the Spring, Summer-Fall and Winter samples collected at site 110 were above the chronic aquatic life criterion. This would represent a baseline condition of non-support of the impaired designated use.

Table 2

NUMBER OF SAMPLES OVER CADMIUM CHRONIC AQUATIC LIFE CRITERION BY FLOW								
Station	**Season**	**0 to 10%**	**10 to 25%**	**25 to 50%**	**50 to 75%**	**75 to 90%**	**90 to 100%**	**Cum. Freq.**
Tar Cr at Picher, Oklahoma (110)	Spring	1	1	0	4	0	0	6/6 = 100%
	Summer/Fall	1	0	0	2	0	0	3/3 = 100%
	Winter	0	1	3	1	1	0	6/6 = 100%

Tar Creek Zinc Samples: Using the three defined seasons: Spring (Apr-Jul), Summer-Fall (Aug-Oct) and Winter (Nov-Mar), excursions were seen in each of these seasons and are outlined in **Table 3**. All of the Spring, Summer-Fall and Winter samples collected at site 110 were above the chronic aquatic life criterion. This would represent a baseline condition of non-support of the impaired designated use.

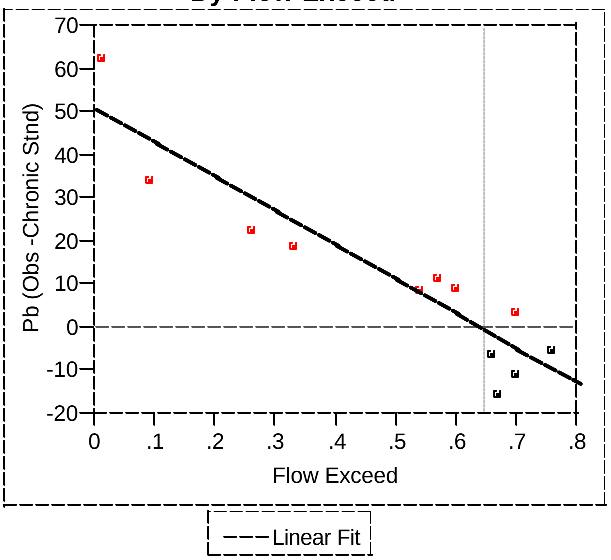
Table 3

NUMBER OF SAMPLES OVER ZINC CHRONIC AQUATIC LIFE CRITERION BY FLOW								
Station	**Season**	**0 to 10%**	**10 to 25%**	**25 to 50%**	**50 to 75%**	**75 to 90%**	**90 to 100%**	**Cum. Freq.**
Tar Cr at Picher, Oklahoma (110)	Spring	1	1	0	4	0	0	6/6 = 100%
	Summer/Fall	1	0	0	2	0	0	3/3 = 100%
	Winter	0	1	3	1	1	0	6/6 = 100%

Lead

The relationship between magnitude of deviation from water quality criterion for lead (in Fg/liter) by flow exceedance and flow are shown in **Figures 6 and 7** below.

Bivariate Fit of Pb (Obs -Chronic Stnd) By Flow Exceed



Linear Fit

Pb (Obs -Chronic Stnd) = 49.521984 - 79.496402*Flow Exceed

Summary of Fit

RSquare	0.863653
RSquare Adj	0.850018
Root Mean Square Error	8.430056
Mean of Response	10.5025
Observations (or Sum Wgts)	12

Analysis of Variance

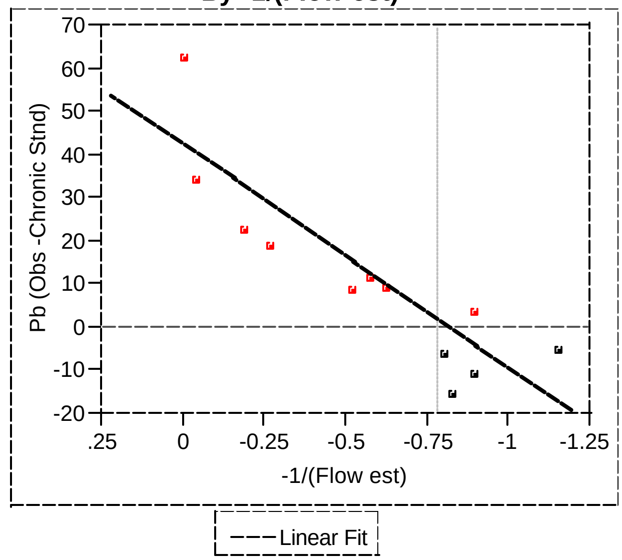
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	4501.4540	4501.45	63.3420
Error	10	710.6584	71.07	Prob > F
C. Total	11	5212.1124		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	49.521984	5.47345	9.05	<.0001
Flow Exceed	-79.4964	9.98852	-7.96	<.0001

Figure 6

Bivariate Fit of Pb (Obs -Chronic Stnd) By -1/(Flow est)



Linear Fit

Pb (Obs -Chronic Stnd) = 39.833346 + 51.633188*(-1/Flow est)

Summary of Fit

RSquare	0.776059
RSquare Adj	0.753665
Root Mean Square Error	10.80372
Mean of Response	10.5025
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	4044.9080	4044.91	34.6547
Error	10	1167.2044	116.72	Prob > F
C. Total	11	5212.1124		0.0002

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	39.833346	5.878061	6.78	<.0001
-1/(Flow est)	51.633188	8.770979	5.89	0.0002

Figure 7

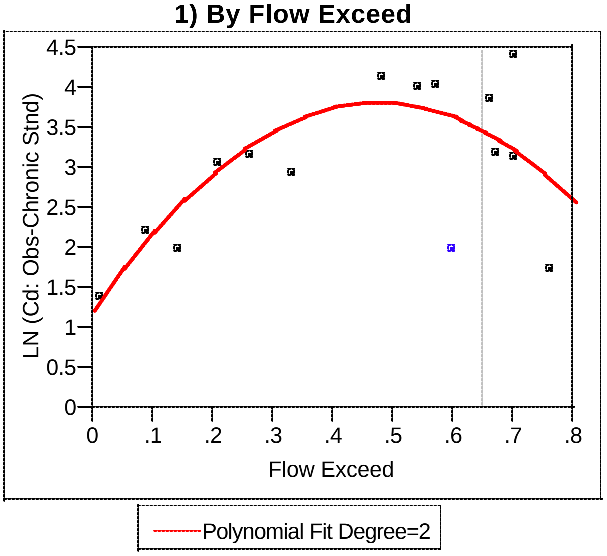
In Figure 6 and 7, the horizontal dashed line at zero on the Y-axis approximates the TMDL for lead. The red markers plotting above this line are historic excursion samples and the black markers plotted below the line are compliant samples.

An estimate of base flow was found from Tar Creek at Miami, Oklahoma, flow data by separating the flow record into two seasons – Winter (November through February) and Summer (July through October). The change in daily flow during each season was calculated and all flows whose change was less than 0.32 for at least 4 consecutive days were used to create a base flow record for each season. The median value for each season was found from this record and those values were averaged for the estimate of base flow at the gage site. This estimate was proportioned to the drainage area at Site 110 and is shown as a vertical dotted line at 65% flow exceedance or 1.27 cfs (-0.7874 for the –1/Flow, X-axis in Figure 7) in Figures 6 and 7. From this, it appears that under base flow conditions Tar Creek is rarely out of compliance with the chronic lead criterion. However, from the historic samples, the runoff condition on Tar Creek is a problem; sampling has always shown excursions from the chronic lead criterion and this identifies the critical flow condition for the Tar Creek lead TMDL.

Cadmium

The relationship between magnitude of deviation from water quality criterion for cadmium (in Fg/liter) by flow exceedance and flow are shown in **Figures 8 and 9** below.

Bivariate Fit of LN (Cd: Obs-Chronic Stnd + 1) By Flow Exceed



Polynomial Fit Degree=2

LN (Cd: Obs-Chronic Stnd) = 1.0795722 + 11.041597*Flow Exceed - 11.674568*Flow Exceed^2

Summary of Fit

RSquare	0.505515
RSquare Adj	0.423101
Root Mean Square Error	0.734934
Mean of Response	2.992843
Observations (or Sum Wgts)	15

Analysis of Variance

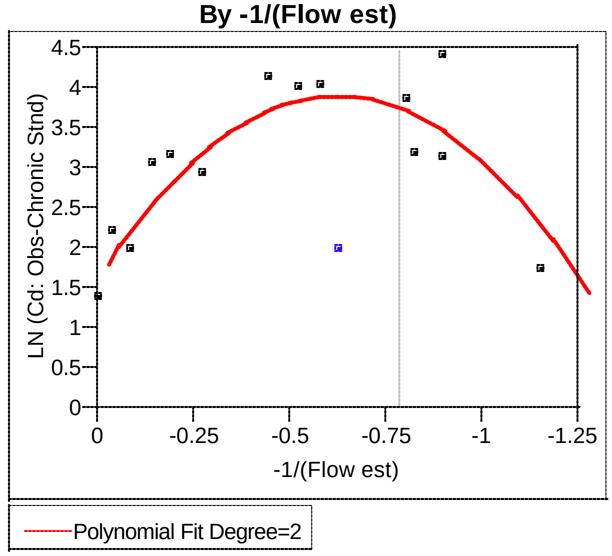
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	6.626112	3.31306	6.1338
Error	12	6.481533	0.54013	Prob > F
C. Total	14	13.107646		0.0146

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.0795722	0.578381	1.87	0.0866
Flow Exceed	11.041597	3.582342	3.08	0.0095
Flow Exceed^2	-11.67457	4.412515	-2.65	0.0213

Figure 8

Bivariate Fit of LN (Cd: Obs-Chronic Stnd +1) By -1/(Flow est)



Polynomial Fit Degree=2

LN (Cd: Obs-Chronic Stnd) = 1.704065 - 6.9216001*(-1/Flow est) - 5.7918003*(-1/Flow est)^2

Summary of Fit

RSquare	0.556922
RSquare Adj	0.483076
Root Mean Square Error	0.695683
Mean of Response	2.992843
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	7.299943	3.64997	7.5416
Error	12	5.807703	0.48398	Prob > F
C. Total	14	13.107646		0.0076

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.704065	0.397716	4.28	0.0011
-1/(Flow est)	-6.9216	1.802269	-3.84	0.0024
-1/(Flow est)^2	-5.7918	1.644606	-3.52	0.0042

Figure 9

In Figure 8 and 9, the horizontal line at zero on the Y-axis approximates the TMDL for cadmium. All samples were in exceedance of the hardness based chronic cadmium criterion; therefore all samples are plotted as positive values. It appears that the relationship between the samples and flow exceedance and flow is no longer the linear relationship that was seen in the lead analysis. A second-degree polynomial was the best fit for this relationship. The blue data point in Figure 8 and 9 may be an outlier in the sample data. Although the removal of this point improves the R-square of the regression substantially (0.68 R-square for Cd by Flow Exceedance and 0.836 for Cd by Flow), the location of the line and its shape do not. Therefore, this possible outlier has been included for this analysis.

The estimate of base flow is again shown as a vertical dotted line at 65% flow exceedance or 1.27 cfs (-0.7874 for the –1/Flow, X-axis in Figure 9) in Figures 8 and 9. From this, it appears that a different relationship exists between cadmium and flow exceedance and flow than that noted in the lead analysis. The magnitude of excursion from the chronic cadmium criterion increases with increasing base flow but then decreases as the runoff component of higher flows become more predominant.

Zinc

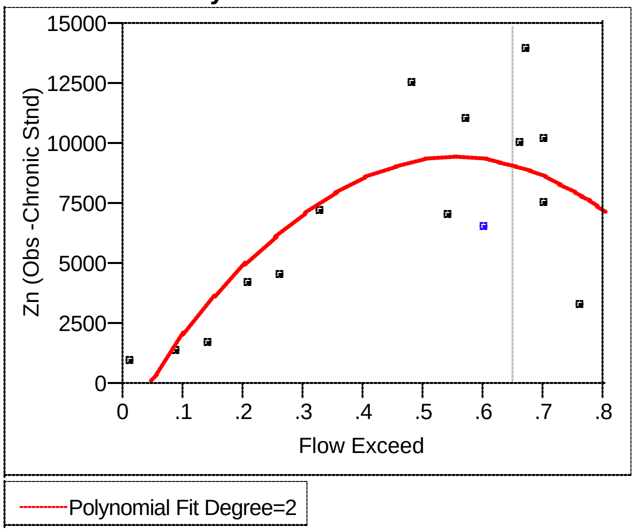
The relationship between magnitude of deviation from water quality criterion for zinc (in Fg/liter) by flow exceedance and flow are shown in **Figures 10 and 11** below.

In Figure 10 and 11, the horizontal line at zero on the Y-axis approximates the TMDL for zinc. All samples were in exceedance of the hardness based chronic zinc criterion, therefore all samples are plotted as positive values. It appears that the relationship between the samples and flow exceedance and flow is, again, not linear. A second-degree polynomial was the best fit for this relationship also. The possible outlier from the cadmium analysis is shown as a blue marker in the zinc sample data. The removal of this point improves the R-square of the regression minimally and the location of the line and its shape change little, which is even more reason to include this sample point in both analyses.

The estimate of base flow is again shown as a vertical dotted line at 65% flow exceedance or 1.27 cfs (-0.7874 for the –1/Flow, X-axis in Figure 11) in Figures 10 and 11. From this, it again appears that the same relationship exists between zinc and flow exceedance and flow that was noted in the cadmium analysis. The magnitude of excursion from the chronic zinc criterion increases with increasing base flow but then decreases as the runoff component of higher flows become more predominant. Note that the magnitude of exceedance for zinc samples is, on average, at least two orders of magnitude higher than the magnitude of exceedances for cadmium samples.

From the above analyses associated with lead, cadmium and zinc samples collected at site 110 on Tar Creek by flow exceedance and flow, it appears that two different trends have surfaced. Those that have generated the lead excursions noted in Tar Creek and those factors generating the cadmium and zinc excursions on Tar Creek. These differences are most likely due to different causes of and sources for the lead and, zinc and cadmium impairments.

Bivariate Fit of Zn (Obs -Chronic Stnd) By Flow Exceed



Polynomial Fit Degree=2
Zn (Obs-Chronic Stnd) = -1767.736 + 40096.91*Flow Exceed - 36426.575*Flow Exceed^2

Summary of Fit

RSquare	0.624847
RSquare Adj	0.562322
Root Mean Square Error	2727.883
Mean of Response	6731.084
Observations (or Sum Wgts)	15

Analysis of Variance

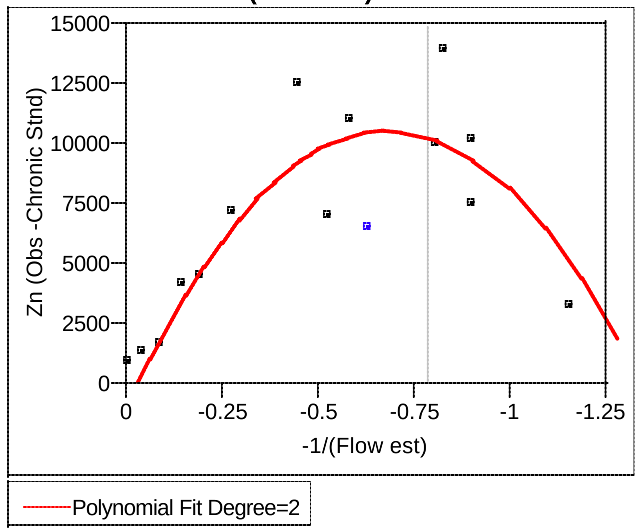
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	148730008	74365004	9.9935
Error	12	89296172	7441347.7	Prob > F
C. Total	14	238026180		0.0028

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1767.736	2146.799	-0.82	0.4263
Flow Exceed	40096.91	13296.72	3.02	0.0108
Flow Exceed^2	-36426.57	16378.11	-2.22	0.0461

Figure 10

Bivariate Fit of Zn (Obs -Chronic Stnd) By -1/(Flow est)



Polynomial Fit Degree=2
Zn (Obs-Chronic Stnd) = -54.73817 - 31832.969*(-1/Flow est) - 24343.875 *-1/Flow est)^2

Summary of Fit

RSquare	0.751838
RSquare Adj	0.710477
Root Mean Square Error	2218.654
Mean of Response	6731.084
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	178957058	89478529	18.1777
Error	12	59069122	4922426.8	Prob > F
C. Total	14	238026180		0.0002

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-54.73817	1268.384	-0.04	0.9663
-1/(Flow est)	-31832.97	5747.748	-5.54	0.0001
-1/(Flow est)^2	-24343.88	5244.933	-4.64	0.0006

Figure 11

Desired Endpoints of Water Quality (Implied Load Capacity) at Site 110 over 2008 – 2012

The ultimate endpoint for this TMDL will be to achieve the chronic lead, cadmium and zinc Kansas Water Quality Standard fully supporting aquatic life. Seasonal variation is not accounted for in this TMDL, since seasonality does not appear to be a factor in the excursions noted in Tar Creek. Excursions have been noted consistently across all seasons and those excursions appear to be related to flow conditions rather than season.

This endpoint will be reached as a result of expected, though unspecified, improvements in riparian, buffer strip and mined land conditions. These improvements will result from implementation of corrective actions and Best Management Practices, as directed by this TMDL. Achievement of this endpoint will provide full support of the aquatic life function of the creek and attain the chronic aquatic life support water quality standard.

In addition to the chronic aquatic life excursions noted for lead, cadmium and zinc, there have been numerous cadmium and zinc acute excursions as well. A separate acute endpoint for these metals will not be developed in this TMDL, since achievement of the chronic endpoint will also address the acute impairment to the aquatic life designated use of Tar Creek.

3. SOURCE INVENTORY AND ASSESSMENT

NPDES: There is one NPDES municipal permitted wastewater discharger within the watershed (**Figure 12**). This system is outlined below in **Table 4**.

Table 4

Facility	NPDES Permit	Federal Permit	Stream Reach	Segment	Design Flow	Type
Treece	M-NE65-OO01	KS0081698	Tar Cr.	19	0.017 MGD	Lagoon

The population projection for Treece to the year 2020 indicates a modest increase. Projections of future water use and resulting wastewater appear to be within the design flows for the current system's treatment capacity. The excursions from the water quality standards appear to occur under higher flow conditions for lead and all flow conditions for cadmium and zinc. Of significance to point sources are the lack of excursions under low flow in all seasons, especially during winter, therefore the point source is not seen as a significant cause of water quality violations for lead in the Tar Creek watershed. The magnitude of excursions under low flow conditions for cadmium and zinc would also rule out any significant contribution from a point source such as Treece with its extremely small design flow.

Mined Land Areas: Metal mining waste areas dominate the lower portion of the watershed near Tar Creek (**Figure 12**). The discharge of drainage for underground zinc and lead mining activities and its associated mine waste (tailing piles) are the cause for elevated zinc, cadmium and, perhaps to a marginally lesser extent, lead in Tar Creek. Mining began about 1850 and by 1950 most of the metal rich ores had been extracted. By 1960 mining and milling operations had ceased. With the cessation of mining, the mines filled with water and this mineralized water is now discharged to Tar Creek. In addition to this direct discharge of mineralized water, tailing piles also contribute mineralized water to streams and tributaries in the area.[1]

[1] Marcher, M.V., Kenny, J.F., *et al*. Hydology of Area 40, Western Region, Interior Coal Province – Kansas, Oklahoma and Missouri. USGS Open File Report 83-266. Page 18.

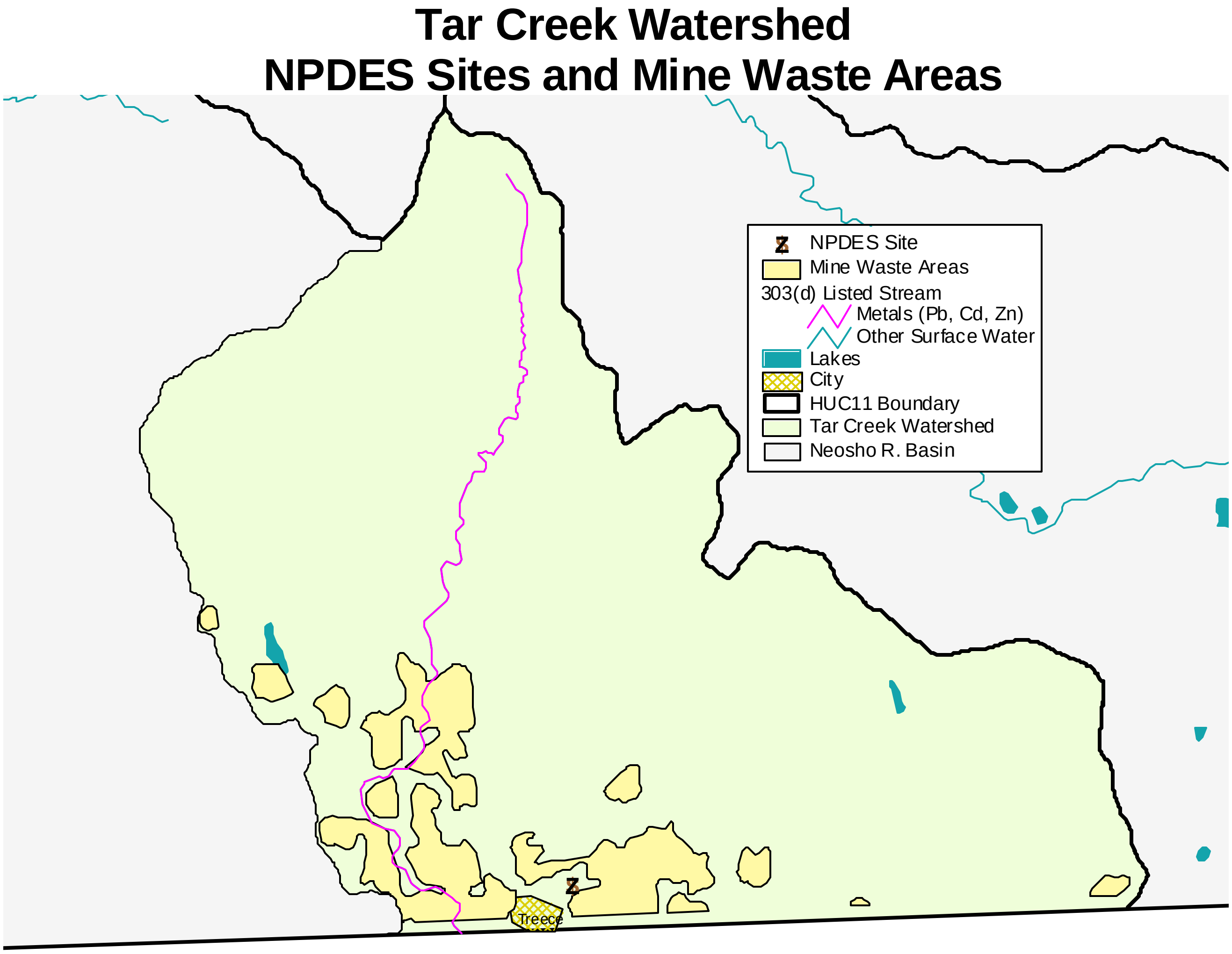
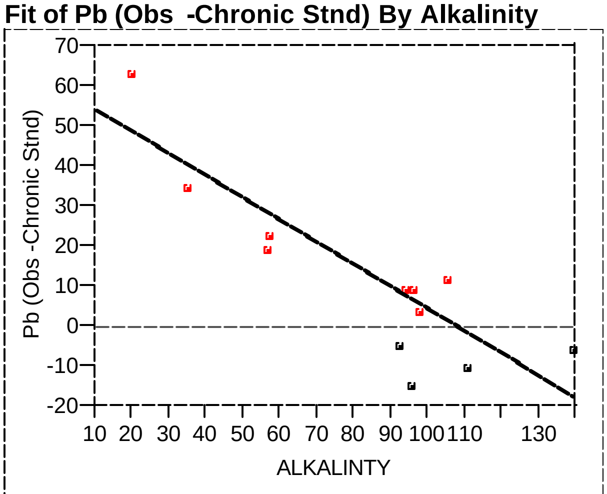


Figure 12

The zinc relationship to flow exceedance and flow in Figures 10 and 11 supports the idea that mined land areas are the cause of the zinc excursions in Tar Creek. Base flow in Tar Creek is primarily derived from the mineralized water from the flooded mines in the watershed and explains the large zinc excursions under this condition. The increase in the magnitude of the zinc excursions up to the transition from base flow to runoff in Figures 10 and 11 may be due to a combination of larger additions from mine tailing contributions (like bank storage releases in streams) in the area, along with larger additions from or numbers of flooded mines contributing. The decrease in the magnitude of zinc excursions as runoff increases is related to both dilution of the zinc concentration in base flow and a reduction in total hardness with increased runoff, which increases the chronic zinc criterion (see hardness-dependent chronic zinc criterion formula on page 1 of this TMDL). This reduction in the magnitude of the zinc excursions during runoff events is still not great enough to drive zinc concentrations in the stream below the chronic water quality criterion. This is probably due to a significant portion of that runoff originating from mined areas (shown in Figure 12). Since the cadmium relationship to flow exceedance and flow closely resembles that of zinc (Figures 8 and 9), these same processes would explain the cause of the cadmium excursions too.

In contrast to the relationship of zinc and cadmium excursions to flow are the lead excursions (Figures 6 and 7). Under base flow conditions in Tar Creek, lead excursions are rare. However, with increasing runoff in the watershed comes an increasing frequency along with an increasing magnitude of lead excursions. This suggests that something about the runoff condition is the cause of the lead excursions in the watershed. The average pH of all samples was 7.1. The average alkalinity of the compliant samples was 110 mg/L and the average alkalinity of the exceedances was 70 mg/L. The relatively high pH of Tar Creek coupled with the relatively high alkalinity at base flow appears to indicate substantial quantities of limestone in the tailing piles in the watershed. This probably limits the lead solubility under base flow conditions[2]. Runoff reduces the alkalinity, which increases the lead solubility. This relationship between the magnitude of deviation from chronic lead criterion and alkalinity is shown in **Figure 13** and may explain the difference noted between lead and flow versus that of zinc and cadmium and flow. Another explanation is that lead may be transported in particulate form from chat piles under higher flows.

Fit of Pb (Obs -Chronic Stnd) By Alkalinity



Linear Fit

Pb (Obs -Chronic Stnd) = 56.594 - 0.5518288 ALKALINITY

Summary of Fit

RSquare	0.75474
RSquare Adj	0.730214
Root Mean Square Error	11.3063
Mean of Response	10.5025
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	3933.7877	3933.79	30.7730
Error	10	1278.3247	127.83	Prob > F
C. Total	11	5212.1124		0.0002

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	56.593999	8.92682	6.34	<.0001
ALKALINITY	-0.551829	0.099476	-5.55	0.0002

Figure 13

[2] Spruill, T. Assessment of Water Resources in Lead-Zinc Mined Areas in Cherokee County, Kansas and Adjacent Areas. USGS Water-Supply Paper 2268. Page 43.

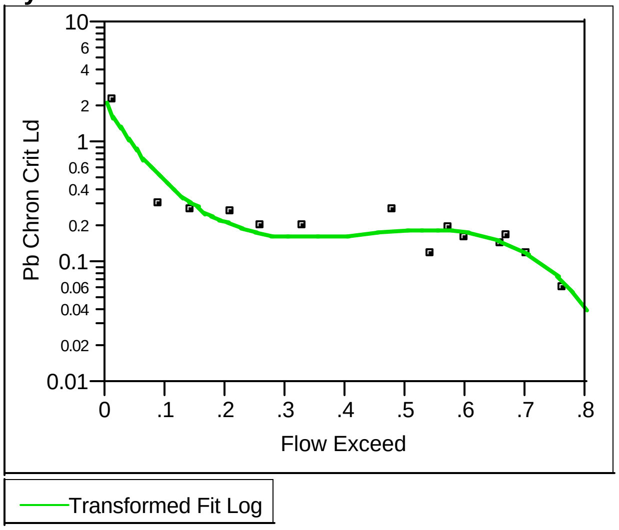
4. ALLOCATION OF POLLUTION REDUCTION RESPONSIBILITY

This is a phased TMDL. Additional monitoring over time will be needed to continually reassess the relationship between flow and lead, zinc and cadmium for the critical flow periods of concern.

<u>Lead</u>

The relationship between the historic lead loadings based on the samples collected in Tar Creek and the chronic aquatic life criterion load for those same samples by flow exceedance are presented in **Figures 14 and 15, respectively**. The regression between the chronic aquatic life criterion and flow exceedance (Figure 14) establishes the TMDL for lead in Tar Creek since this condition represent the maximum lead load to Tar Creek that still meets the chronic aquatic life designated use. The regression between the sample lead load and flow exceedance (Figure 15) shows the historic condition of lead loading in Tar Creek to date. **Figure 16** is an overlay graph of these two conditions and the data used to create the regression that defines them. An explicit Margin of Safety (MOS) (shown in Figure 16) was established by reducing the total hardness used to calculate the chronic lead criterion by 10%. The load was found and plotted by flow exceedance as before and a regression was established for the relationship (**Figure 17)**. The difference between the historic condition and the TMDL – MOS curve creates the necessary load reduction for lead in Tar Creek. The area under the TMDL – MOS curve is the load allocated to point and non-point sources in the watershed. The point where the historic condition in Figure 16 drops below the TMDL –MOS curve demarcates the transition from the historic compliant condition to the impaired flow condition in the watershed. No lead load reduction is needed for the compliant flow condition.

Bivariate Fit of Pb Chronic Load (lbs/day) By Flow Exceedance



Transformed Fit Log

Log(Pb Chron Crit Ld) = 0.6964395 - 19.661774*Flow Exceed + 48.133183*Flow Exceed^2 - 37.116928*Flow Exceed^3

Summary of Fit

RSquare	0.914808
RSquare Adj	0.882862
Root Mean Square Error	0.299255
Mean of Response	-1.69594
Observations (or Sum Wgts)	12

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	7.6931889	2.56440	28.6353
Error	8	0.7164287	0.08955	Prob > F
C. Total	11	8.4096176		0.0001

Parameter Estimates

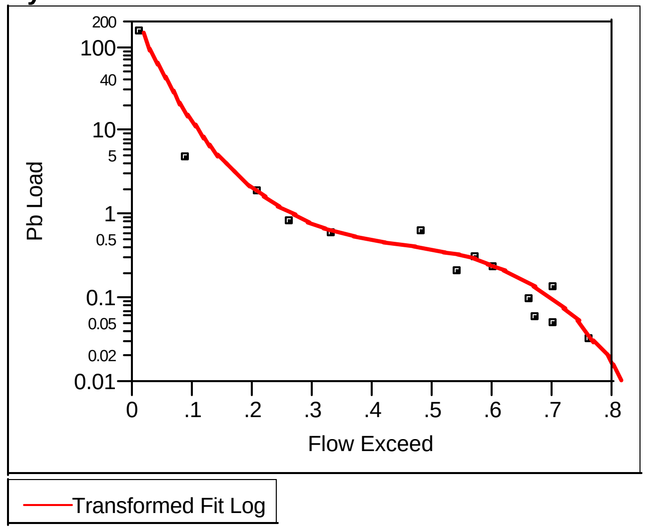
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.6964395	0.294843	2.36	0.0458
Flow Exceed	-19.66177	3.621414	-5.43	0.0006
Flow Exceed^2	48.133183	11.00513	4.37	0.0024
Flow Exceed^3	-37.11693	9.284056	-4.00	0.0040

Fit Measured on Original Scale

Sum of Squared Error	0.3067771
Root Mean Square Error	0.1751505
RSquare	0.9177932
Sum of Residuals	0.3687718

Figure 14

Bivariate Fit of Sample Pb Load (lbs/day) By Flow Exceedance



Transformed Fit Log

Log(Pb Load) = 4.9510656 - 35.485039*Flow Exceed + 75.827652*Flow Exceed^2 - 58.088398*Flow Exceed^3

Summary of Fit

RSquare	0.962267
RSquare Adj	0.950947
Root Mean Square Error	0.489661
Mean of Response	-0.87255
Observations (or Sum Wgts)	14

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	61.145149	20.3817	85.0062
Error	10	2.397675	0.2398	Prob > F
C. Total	13	63.542824		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.9510656	0.48069	10.30	<.0001
Flow Exceed	-35.48504	5.396478	-6.58	<.0001
Flow Exceed^2	75.827652	16.16487	4.69	0.0009
Flow Exceed^3	-58.0884	13.67219	-4.25	0.0017

Fit Measured on Original Scale

Sum of Squared Error	2704.2779
Root Mean Square Error	15.011878
RSquare	0.8720879
Sum of Residuals	46.832462

Figure 15

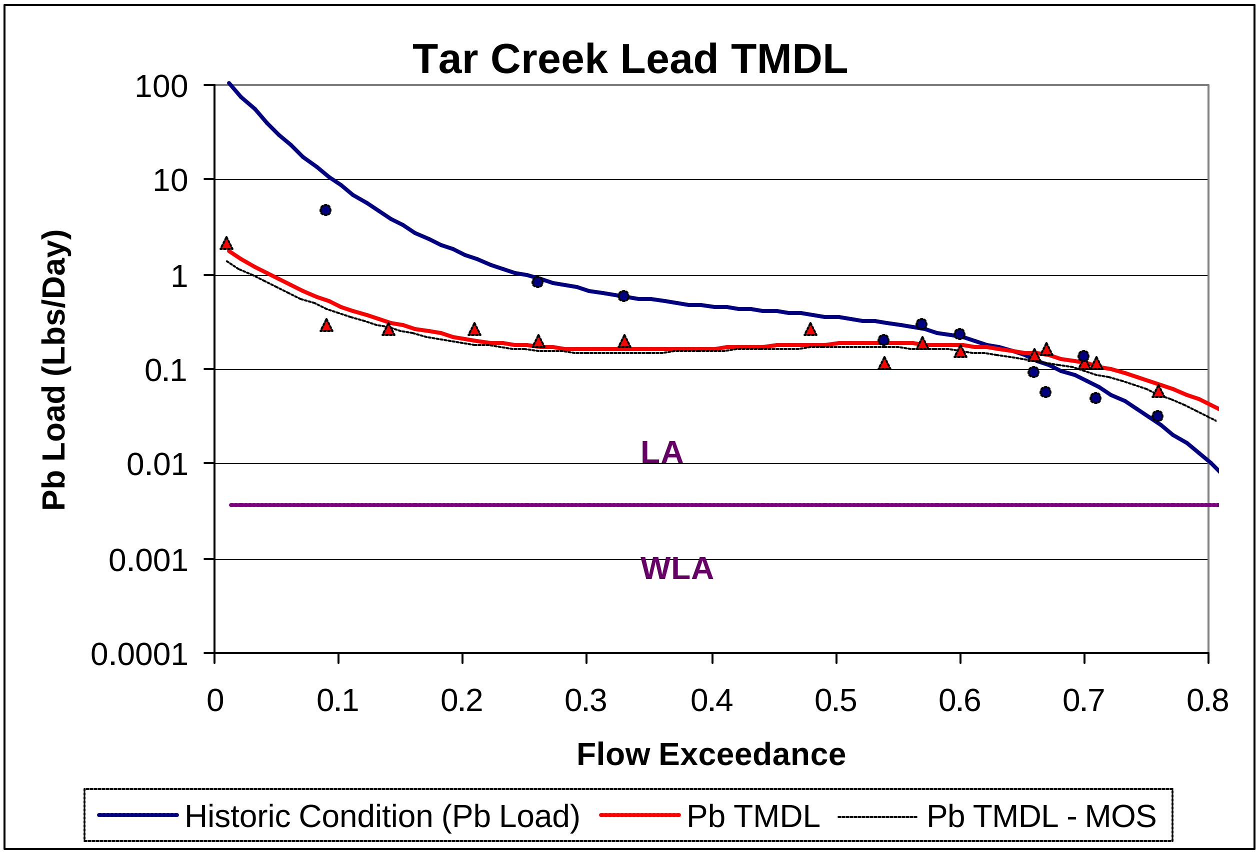
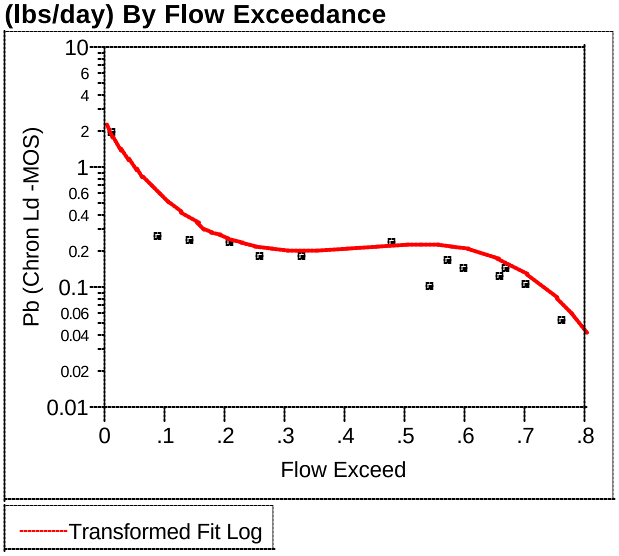


Figure 16

Bivariate Fit of Pb (Chronic Load – MOS) (lbs/day) By Flow Exceedance



Transformed Fit Log

Log(Pb (Chron Ld -MOS)) = 0.5051521 - 18.742068*Flow Exceed + 46.902923*Flow Exceed^2 - 37.074472*Flow Exceed^3

Summary of Fit

RSquare	0.893107
RSquare Adj	0.863954
Root Mean Square Error	0.29065
Mean of Response	-1.75703
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	7.7640342	2.58801	30.6355
Error	11	0.9292516	0.08448	Prob > F
C. Total	14	8.6932857		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.5051521	0.283415	1.78	0.1023
Flow Exceed	-18.74207	3.145771	-5.96	<.0001
Flow Exceed^2	46.902923	9.288272	5.05	0.0004
Flow Exceed^3	-37.07447	7.837211	-4.73	0.0006

Fit Measured on Original Scale

Sum of Squared Error	0.2924348
Root Mean Square Error	0.1499833
RSquare	0.8957782
Sum of Residuals	0.3720194

Figure 17

Point Sources (Lead): A current Wasteload Allocation (WLA) of 0.003463 pounds per day is established by this TMDL (**Figure 16**) and is based on the city of Treece design flow (0.026 cfs) and the chronic lead criterion (0.02469 mg/L) calculated from the maximum total hardness (500 mg/L) sampled under low flow conditions.

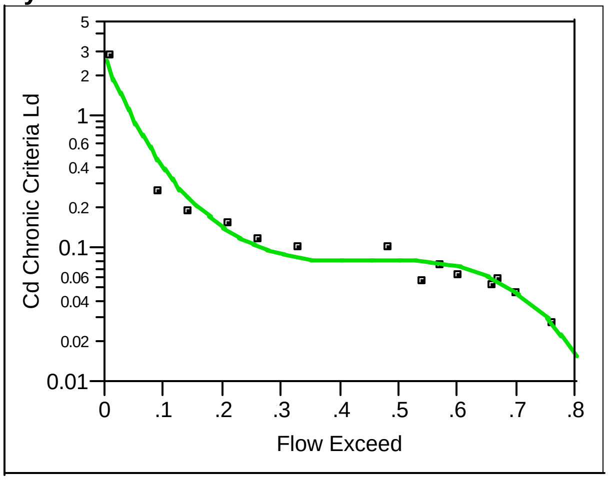
Non-Point Sources (Lead): Based on the prior assessment of sources, the distribution of excursions from water quality standards at site 110 and the relationship of those excursions to runoff conditions and available sources, non-point sources are seen as the primary contributing factor to the lead excursions in the watershed.

The samples from the Tar Creek watershed show lead violations only occurred under run off conditions. The Load Allocation (LA) assigns responsibility for reducing the in stream lead loads at site 110 for flows greater than 1.27 cfs (65% exceedance) and maintaining historic lead loads for flows less than or equal to1.27 cfs. This LA is displayed graphically in **Figure 16** by the integrated area between the TMDL – MOS curve and the WLA line for flows greater than 65% exceedance and the integrated area between the historic (compliant) condition line and the WLA for flow equal to or less than 65% exceedance. Sediment control practices such as buffer strips, grassed waterways and reclamation activities on mined land areas should help reduce the non-point source lead load under run off conditions in the watershed.

Cadmium

The relationship between the historic cadmium loadings based on the samples collected in Tar Creek and the chronic aquatic life criterion load for those same samples by flow exceedance are presented in **Figures 18 and 19, respectively**. The regression between the chronic cadmium aquatic life criterion and flow exceedance (Figure 18) establishes the TMDL for cadmium in Tar Creek since this condition represent the maximum cadmium load to Tar Creek that still meets the chronic aquatic life designated use. The regression between the sample cadmium load and flow exceedance (Figure 19) shows the historic condition of cadmium loading in Tar Creek to date. **Figure 20** is an overlay graph of these two conditions and the data used to create the regression that defines them. An explicit Margin of Safety (MOS) (shown in Figure 20) was established by reducing the total hardness used to calculate the chronic cadmium criterion by 10%. The load was found and plotted by flow exceedance as before and a regression was established for the relationship (**Figure 21)**. The difference between the historic condition and the TMDL – MOS curve creates the necessary load reduction for cadmium in Tar Creek. The area under the TMDL – MOS curve is the load allocated to point and non-point sources in the watershed.

Bivariate Fit of Cd Chronic Load (lbs/day) By Flow Exceedance



Transformed Fit Log

Transformed Fit Log

Log(Cd Chronic Criteria Ld) = 0.8866852 - 23.386964*Flow Exceed + 52.478077*Flow Exceed^2 - 38.951044*Flow Exceed^3

Summary of Fit

RSquare	0.956899
RSquare Adj	0.945144
Root Mean Square Error	0.256925
Mean of Response	-2.31418
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	16.120748	5.37358	81.4052
Error	11	0.726114	0.06601	Prob > F
C. Total	14	16.846862		<.0001

Parameter Estimates

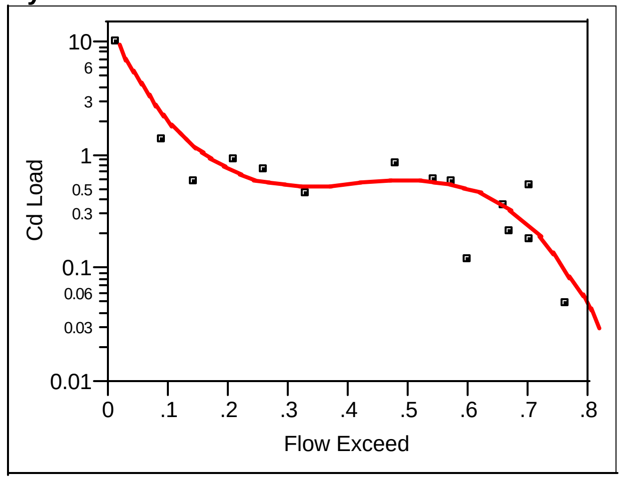
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8866852	0.250529	3.54	0.0046
Flow Exceed	-23.38696	2.780756	-8.41	<.0001
Flow Exceed^2	52.478077	8.210519	6.39	<.0001
Flow Exceed^3	-38.95104	6.927831	-5.62	0.0002

Fit Measured on Original Scale

Sum of Squared Error	0.6565309
Root Mean Square Error	0.2247273
RSquare	0.8987202
Sum of Residuals	0.6142178

Figure 18

Bivariate Fit of Cd Sample Load (lbs/day) By Flow Exceedance



Transformed Fit Log

Transformed Fit Log

Log(Cd Load) = 2.2163859 - 23.618112*Flow Exceed + 62.092942*Flow Exceed^2 - 51.96901*Flow Exceed^3

Summary of Fit

RSquare	0.799195
RSquare Adj	0.74443
Root Mean Square Error	0.606481
Mean of Response	-0.715
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	16.103008	5.36767	14.5932
Error	11	4.046017	0.36782	Prob > F
C. Total	14	20.149025		0.0004

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.2163859	0.591384	3.75	0.0032
Flow Exceed	-23.61811	6.564087	-3.60	0.0042
Flow Exceed^2	62.092942	19.38127	3.20	0.0084
Flow Exceed^3	-51.96901	16.35343	-3.18	0.0088

Fit Measured on Original Scale

Sum of Squared Error	6.230669
Root Mean Square Error	0.6923021
RSquare	0.9209065
Sum of Residuals	2.3197466

Figure 19

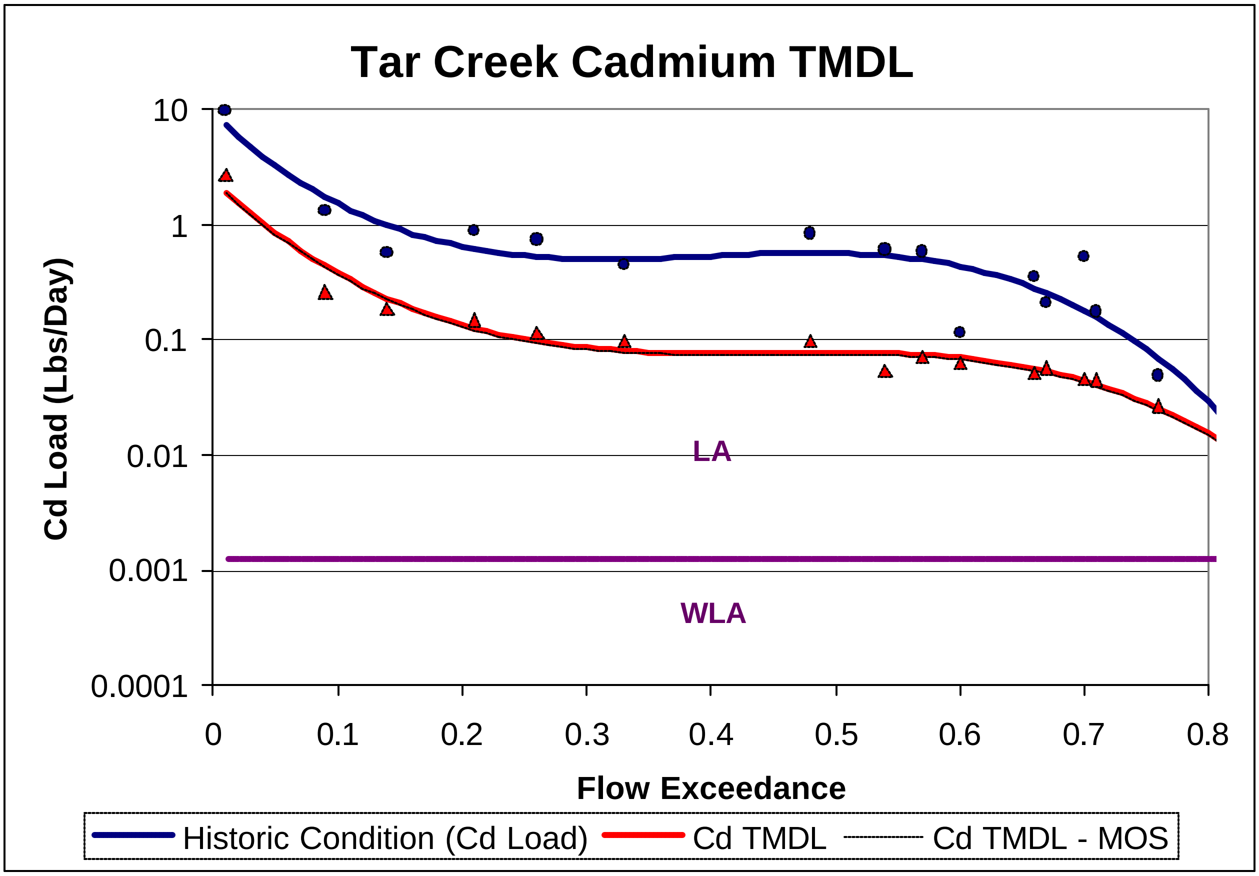
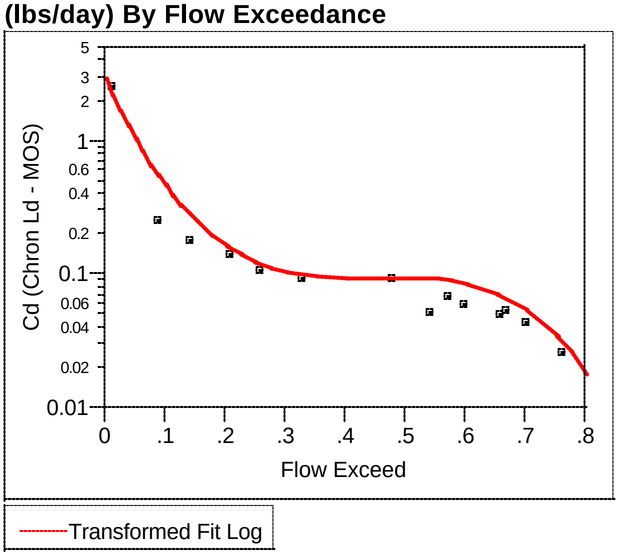


Figure 20

Bivariate Fit of Cd (Chronic Load – MOS) (lbs/day) By Flow Exceedance



Transformed Fit Log

Log(Cd (Chron Ld - MOS) = 0.8051129 - 23.384663*Flow Exceed + 52.460074*Flow Exceed^2 - 38.934193*Flow Exceed^3

Summary of Fit

RSquare	0.957238
RSquare Adj	0.945575
Root Mean Square Error	0.25599
Mean of Response	-2.39665
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	16.136051	5.37868	82.0783
Error	11	0.720842	0.06553	Prob > F
C. Total	14	16.856894		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8051129	0.249618	3.23	0.0081
Flow Exceed	-23.38466	2.770643	-8.44	<.0001
Flow Exceed^2	52.460074	8.180661	6.41	<.0001
Flow Exceed^3	-38.93419	6.902637	-5.64	0.0002

Fit Measured on Original Scale

Sum of Squared Error	0.5522496
Root Mean Square Error	0.2061086
RSquare	0.8994222
Sum of Residuals	0.5629551

Figure 21

Point Sources (Cadmium): A current Wasteload Allocation (WLA) of 0.001222 pounds per day is established by this TMDL (**Figure 20**) and is based on the city of Treece design flow (0.026 cfs) and the chronic cadmium criterion (0.00871 mg/L) calculated from the maximum total hardness (500 mg/L) sampled under low flow conditions.

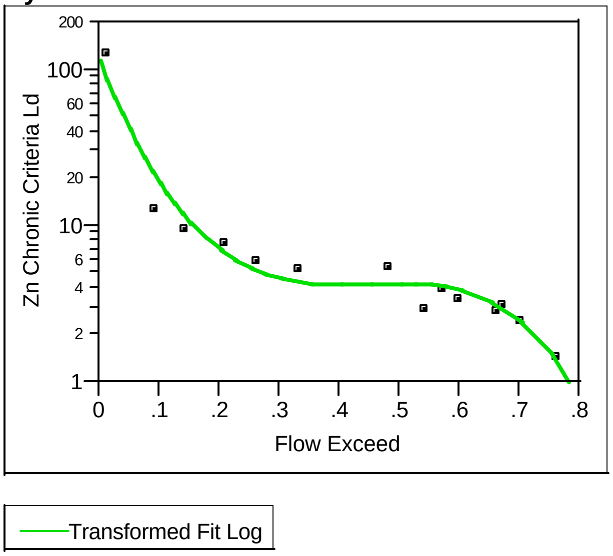
Non-Point Sources (Cadmium): Based on the prior assessment of sources, the distribution of excursions from water quality standards at site 110 and the relationship of those excursions to base flow, runoff conditions and available sources, non-point sources are seen as the primary contributing factor to the cadmium excursions in the watershed.

The samples collected from the Tar Creek watershed show cadmium violations occurred under all flow conditions. The Load Allocation (LA) assigns responsibility for reducing the in stream cadmium loads at site 110 across all flows. This LA is displayed graphically in **Figure 20** by the integrated area between the TMDL – MOS curve and the WLA line for all flows. Based upon the assessment of sources, only reclamation activities on mined land areas would help reduce the non-point source cadmium loads in the watershed.

<u>Zinc</u>

The relationship between the historic zinc loadings based on the samples collected in Tar Creek and the chronic aquatic life criterion load for those same samples by flow exceedance are presented in **Figures 22 and 23, respectively**. The regression between the chronic zinc aquatic life criterion and flow exceedance (Figure 22) establishes the TMDL for zinc in Tar Creek since this condition represent the maximum zinc load to Tar Creek that still meets the chronic aquatic life designated use. The regression between the sample zinc load and flow exceedance (Figure 23) shows the historic condition of zinc loading in Tar Creek to date. **Figure 24** is an overlay graph of these two conditions and the data used to create the regression that defines them. An explicit Margin of Safety (MOS) (shown in Figure 24) was established by reducing the total hardness used to calculate the chronic zinc criterion by 10%. The load was found and plotted by flow exceedance as before and a regression was established for the relationship (**Figure 25)**. The difference between the historic condition and the TMDL – MOS curve creates the necessary load reduction for zinc in Tar Creek. The area under the TMDL – MOS curve is the load allocated to point and non-point sources in the watershed.

Bivariate Fit of Zn Chronic Load (lbs/day) By Flow Exceedance



Transformed Fit Log

Log(Zn Chronic Criteria Ld) = 4.7077559 - 22.795069*Flow Exceed + 51.76153*Flow Exceed^2 - 38.704251*Flow Exceed^3

Summary of Fit

RSquare	0.95269
RSquare Adj	0.939787
Root Mean Square Error	0.259012
Mean of Response	1.626168
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	14.860415	4.95347	73.8365
Error	11	0.737957	0.06709	Prob > F
C. Total	14	15.598373		<.0001

Parameter Estimates

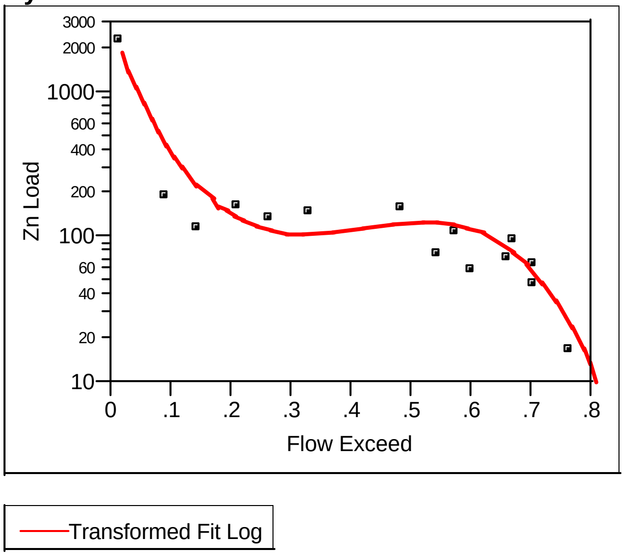
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.7077559	0.252564	18.64	<.0001
Flow Exceed	-22.79507	2.803342	-8.13	<.0001
Flow Exceed^2	51.76153	8.277208	6.25	<.0001
Flow Exceed^3	-38.70425	6.984101	-5.54	0.0002

Fit Measured on Original Scale

Sum of Squared Error	1341.6861
Root Mean Square Error	10.159066
RSquare	0.899992
Sum of Residuals	27.387406

Figure 22

Bivariate Fit of Zn Sample Load (lbs/day) By Flow Exceedance



Transformed Fit Log

Log(Zn Load) = 7.4851488 - 23.737246*Flow Exceed + 62.412486*Flow Exceed^2 - 51.343098*Flow Exceed^3

Summary of Fit

RSquare	0.869332
RSquare Adj	0.833695
Root Mean Square Er ror	0.423547
Mean of Response	4.685592
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	13.128372	4.37612	24.3942
Error	11	1.973309	0.17939	Prob > F
C. Total	14	15.101682		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7.4851488	0.413003	18.12	<.0001
Flow Exceed	-23.73725	4.584142	-5.18	0.0003
Flow Exceed^2	62.412486	13.53524	4.61	0.0008
Flow Exceed^3	-51.3431	11.42069	-4.50	0.0009

Fit Measured on Original Scale

Sum of Squared Error	698000.68
Root Mean Square Error	231.71612
RSquare	0.8354248
Sum of Residuals	687.06469

Figure 23

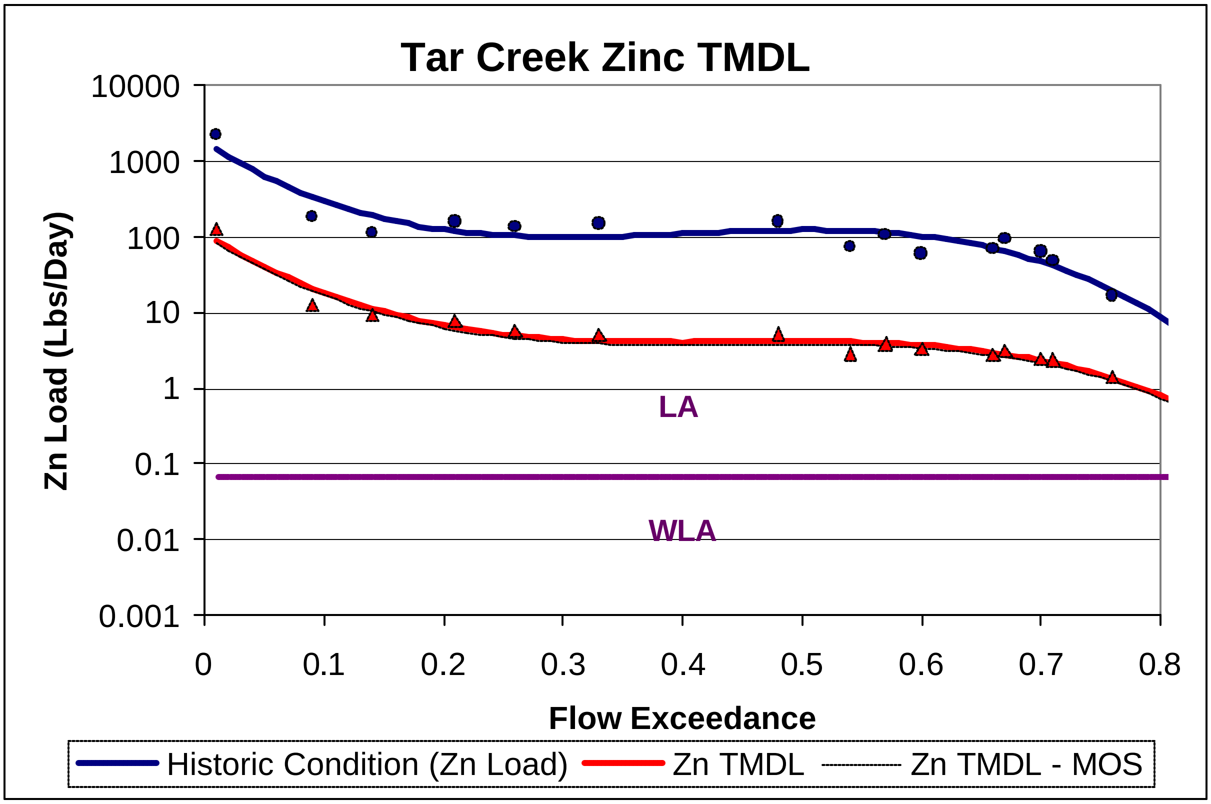
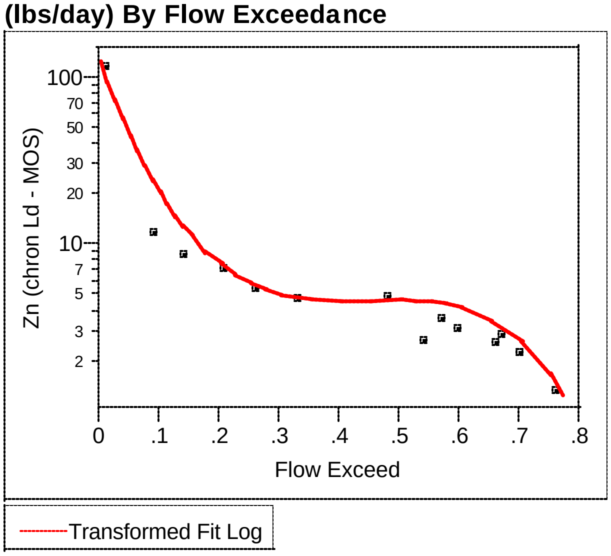


Figure 24

Bivariate Fit of Zn (Chronic Load – MOS) (lbs/day) By Flow Exceedance



Transformed Fit Log

Log(Zn (Chronic Ld - MOS)) = 4.6184215 - 22.794282*Flow Exceed + 51.75937*Flow Exceed^2 - 38.702576*Flow Exceed^3

Summary of Fit

RSquare	0.952691
RSquare Adj	0.939788
Root Mean Square Error	0.259007
Mean of Response	1.536899
Observations (or Sum Wgts)	15

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	14.860029	4.95334	73.8374
Error	11	0.737929	0.06708	Prob > F
C. Total	14	15.597958		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	4.6184215	0.252559	18.29	<.0001
Flow Exceed	-22.79428	2.803289	-8.13	<.0001
Flow Exceed^2	51.75937	8.277052	6.25	<.0001
Flow Exceed^3	-38.70258	6.983969	-5.54	0.0002

Fit Measured on Original Scale

Sum of Squared Error	1122.0897
Root Mean Square Error	9.2905648
RSquare	0.8999971
Sum of Residuals	25.04552

Figure 25

Point Sources (Zinc): A current Wasteload Allocation (WLA) of 0.065732 pounds per day is established by this TMDL (**Figure 24**) and is based on the city of Treece design flow (0.026 cfs) and the chronic zinc criterion (0.46861 mg/L) calculated from the maximum total hardness (500 mg/L) sampled under low flow conditions.

Non-Point Sources (Zinc): Based on the prior assessment of sources, the distribution of excursions from water quality standards at site 110 and the relationship of those excursions to base flow, runoff conditions and available sources, non-point sources are seen as the primary contributing factor to the zinc excursions in the watershed.

The samples from the Tar Creek watershed show zinc violations occurred under all flow conditions. The Load Allocation (LA) assigns responsibility for reducing the in stream zinc loads at site 110 across all flows. This LA is displayed graphically in **Figure 24** by the integrated area between the TMDL – MOS curve and the WLA line for all flows. Based upon the assessment of sources, only reclamation activities on mined land areas would help reduce the non-point source cadmium loads in the watershed.

Defined Margin of Safety: An explicit Margin of Safety (MOS) was established by using 10% reduction of the observed total hardness used to calculate the chronic lead, cadmium and zinc aquatic life criterion. After the application of this reduction, the load was found and plotted by flow exceedance and a regression was established for the relationship (see Figures 17, 21 and 25 for the lead, cadmium and zinc regression, which is displayed in the TMDLs for lead, cadmium and zinc in Figures 16, 20 and 24, respectively).

State Water Plan Implementation Priority: Because high frequency and magnitude of excursions seen in the Tar Creek watershed, this TMDL will be a Medium Priority for implementation.

Unified Watershed Assessment Priority Ranking: This watershed lies within the Lake O' the Cherokees Basin (HUC 8: 11070206) with a priority ranking of 64 (Low Priority for restoration work).

Priority HUC 11s and Stream Segments: Priority focus of implementation will concentrate on installing best management practices adjacent to main stem segments and flow contributing tributaries in the watershed and reclamation activities on mined land areas.

5. IMPLEMENTATION

Desired Implementation Activities

1. Where needed, create/restore riparian vegetation along target stream segments.
2. Install grass buffer strips where needed along streams.
3. Explore and enhance opportunities for mined land area reclamation projects.

Implementation Programs Guidance

Superfund Program – KDHE & EPA

a. Guide mined land area reclamation projects.

Non-Point Source Pollution Technical Assistance - KDHE

a. Guide federal programs such as the Environmental Quality Improvement Program, which are dedicated to priority subbasins through the Unified Watershed Assessment, to priority stream segments identified by this TMDL.

Riparian Protection Program - SCC

a. Develop riparian restoration projects along targeted stream segments, especially those areas with baseflow.

Buffer Initiative Program - SCC

a. Install grass buffer strips near streams.

b. Leverage Conservation Reserve Enhancement Program to hold riparian land out of production.

Local Environmental Protection Program - KDHE

a. Inspect and repair on-site waste systems within 500 feet of priority stream segments.

Timeframe for Implementation: Water quality improvement activities are encouraged at the local level prior to 2007. Funding for installing pollution reduction practices should be allocated within the stream drainage after the year 2007. Evaluation of metal sources to the stream and identification of potential management techniques should occur prior to 2007.

Targeted Participants: Primary participants for implementation will be the Superfund Programs with the Kansas Department of Health and Environment and the U.S. Environmental Protection Agency.

Milestone for 2007: The year 2007 marks the midpoint of the ten-year implementation window for the watershed. At that point in time, sampled data from Tar Creek should indicate probable sources of lead, cadmium, and zinc and plans in place to initiate implementation.

Delivery Agents: The primary delivery agents for program participation will be the Kansas Department of Health and Environment, the U.S. Environmental Protection Agency, and conservation districts for programs of the State Conservation Commission.

Reasonable Assurances:

Authorities: The following authorities may be used to direct activities in the watershed to reduce pollution.

1. K.S.A. 65-164 and 165 empowers the Secretary of KDHE to regulate the discharge of sewage into the waters of the state.

2. K.S.A. 65-171d empowers the Secretary of KDHE to prevent water pollution and to protect the beneficial uses of the waters of the state through required treatment of sewage and established water quality standards and to require permits by persons having a potential to discharge pollutants into the waters of the state.

3. K.A.R. 28-16-69 to -71 implements water quality protection by KDHE through the establishment and administration of critical water quality management areas on a watershed basis.

4. K.S.A. 2-1915 empowers the State Conservation Commission to develop programs to assist the protection, conservation and management of soil and water resources in the state, including riparian areas.

5. K.S.A. 75-5657 empowers the State Conservation Commission to provide financial assistance for local project work plans developed to control non-point source pollution.

6. K.S.A. 82a-901, *et seq*. empowers the Kansas Water Office to develop a state water plan directing the protection and maintenance of surface water quality for the waters of the state.

7. K.S.A. 82a-951 creates the State Water Plan Fund to finance the implementation of the *Kansas Water Plan*.

8. The *Kansas Water Plan* and the Neosho Basin Plan provide the guidance to state agencies to coordinate programs intent on protecting water quality and to target those programs to geographic areas of the state for high priority in implementation.

Funding: The State Water Plan Fund, annually generates $16-18 million and is the primary funding mechanism for implementing water quality protection and pollution reduction activities in the state through the *Kansas Water Plan*. The state water planning process, overseen by the Kansas Water Office, coordinates and directs programs and funding toward watersheds and water resources of highest priority. Typically, the state allocates at least 50% of the fund to programs supporting water quality protection. This watershed and its TMDL are a Medium Priority consideration.

Effectiveness: Buffer strips are touted as a means to filter sediment before it reaches a stream and riparian restoration projects have been acclaimed as a significant means of stream bank stabilization. The key to effectiveness is participation within a finite subwatershed to direct resources to the activities influencing water quality. The milestones established under this

TMDL are intended to gauge the level of participation in those programs implementing this TMDL.

6. MONITORING

KDHE will continue to collect bimonthly samples at rotational Station 110 in 2005 and 2009 including lead, cadmium and zinc samples, in order to assess progress and success in implementing this TMDL toward reaching its endpoint. Should impaired status remain, the desired endpoints under this TMDL will be refined and more intensive sampling may need to be conducted under specified flow conditions over the period 2008-2012.

Local program management needs to identify its targeted participants of state assistance programs for implementing this TMDL. This information should be collected in 2004 -2005 in order to support appropriate implementation projects.

7. FEEDBACK

Public Meetings: Public meetings to discuss TMDLs in the Neosho Basin were held January 9, 2002 in Burlington and March 4, 2002 in Council Grove. An active Internet Web site was established at http://www.kdhe.state.ks.us/tmdl/ to convey information to the public on the general establishment of TMDLs and specific TMDLs for the Neosho Basin.

Public Hearing: Public Hearings on the TMDLs of the Neosho Basin were held in Burlington and Parsons on June 3, 2002.

Basin Advisory Committee: The Neosho Basin Advisory Committee met to discuss the TMDLs in the basin on October 2, 2001, January 9, March 4, and June 3, 2002.

Milestone Evaluation: In 2007, evaluation will be made as to the degree of implementation which has occurred within the watershed and current condition of Tar Creek. Subsequent decisions will be made regarding the implementation approach and follow up of additional implementation in the watershed.

Consideration for 303(d) Delisting: The stream will be evaluated for delisting under Section 303(d), based on the monitoring data over the period 2007-2011. Therefore, the decision for delisting will come about in the preparation of the 2012 303(d) list. Should modifications be made to the applicable water quality criteria during the ten-year implementation period, consideration for delisting, desired endpoints of this TMDL and implementation activities may be adjusted accordingly.

Incorporation into Continuing Planning Process, Water Quality Management Plan and the Kansas Water Planning Process: Under the current version of the Continuing Planning Process, the next anticipated revision will come in 2003 which will emphasize revision of the Water Quality Management Plan. At that time, incorporation of this TMDL will be made into both documents. Recommendations of this TMDL will be considered in *Kansas Water Plan* implementation decisions under the State Water Planning Process for Fiscal Years 2003-2007.

9/17/04